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P.A. Herrmann

J.A. French

G.B. Dehart

K.S. Rosengren

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Essentialist Reasoning and Knowledge Effects on Biological Reasoning in Young Children

Patricia A. Herrmann *The University of Texas at Austin*
Jason A. French *Northwestern University*
Ganie B. DeHart *State University of New York (SUNY)–Geneseo*
Karl S. Rosengren *Northwestern University*

Biological kinds undergo a variety of changes during their life span, and these changes vary in degree by organism. Understanding that an organism, such as a caterpillar, maintains category identity over its life span despite dramatic changes is a key concept in biological reasoning. At present, we know little about the developmental trajectory of children's understanding of dramatic life-cycle changes and how this might relate to their understanding of evolution. We suggest that this understanding is a key precursor to later understanding of evolutionary change. Two studies examined the impact of age and knowledge on children's biological reasoning about living kinds that undergo a range of natural life-span changes—from subtle to dramatic. The participants, who were 3, 4, and 7 years old, were shown paired pictures of juvenile and adult animals and asked to endorse biological or nonbiological causal mechanisms to account for life-span change. Additionally, reasoning of 3- and 4-year-old participants was compared before and after exposure to caterpillars transforming into butterflies. The results are framed in terms of a developmental trajectory in essentialist reasoning, a cognitive bias that has been associated with difficulties in understanding and accepting evolution.

Life-cycle changes can be both subtle and dramatic. For some species, growth involves primarily morphological changes that subtly turn a cuddly kitten into a full-grown cat over a period of months. In contrast,

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Patricia A. Herrmann, Department of Psychology; Jason A. French, Department of Psychology, Ganie B. DeHart, Department of Psychology; Karl S. Rosengren, Department of Psychology.

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Address correspondence to Patricia A. Herrmann, Department of Psychology, The University of Texas at Austin, 1 University Station A8000, Austin, TX 78712-0187. Phone: (512) 471-1157. Fax: (512) 471-6175. E-mail: herrmann@psy.utexas.edu.

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the maturation of a monarch caterpillar involves growing larger and then undergoing a dramatic transformation into an adult form that varies in size, color, and shape. Between these two extremes are organisms such as birds, whose life-cycle changes involve a shift in color and texture as the furry, gray down of a gosling gives rise to the snowy white feathers of a swan. To what extent are children of different ages sensitive to these variations in changes that occur over species' life spans? And to what extent do children of different ages view these as natural biological changes?

These issues are important because by examining how children think about these kinds of biological changes we may gain insight into how they reason about changes in species over time. Thus, we suggest that an understanding that individuals can change dramatically over their life cycles as part of natural, biological processes may be an important precursor to grasping key concepts related to evolution, such as variation. If children are unwilling to accept instances of possible biological change, such as tadpoles turning into frogs, it is unclear how they could ever grasp the concept of species change over time, which involves equally dramatic changes in appearance and structure.

Examining children's knowledge of these types of natural changes may be particularly informative for examining essentialist reasoning in children, a type of reasoning that may dominate young children's and even adults' thinking (Gelman, 2003; Medin & Ortony, 1989). Psychological essentialism is a belief that membership in a category is defined by an unseen, causal property or essence (Medin & Ortony, 1989). This form of reasoning has been viewed as a barrier to both children's and adults' understanding of evolution by causing participants to overlook individual differences within a species (Coley & Muratore, 2012; Gelman & Rhodes, 2012; Shtulman & Calabi, 2012).

Whereas the dramatic change of a caterpillar's metamorphosis into a butterfly occurs in the natural world, there are many species that do not undergo natural dramatic change. Kittens do not shed their fur, grow feathers and wings, and become birdlike creatures (Keil, 1989; Rips, 1989). No natural biological mechanism can render these changes. This kind of information regarding which changes are typical and which are atypical is an important aspect of category knowledge about biological entities. Nontypical and potentially impossible changes violate our understanding of what constitutes categories of familiar animals. Gaining more insight into how children reason about category membership, the types of change they believe are biologically possible, and whether children treat the boundaries between species as permeable or impenetrable may lead to new insights about why the concept of evolution is so difficult for many children and adults to understand and accept (Legare, Lane, & Evans, 2013; Rosengren, Brem, Evans, & Sinatra, 2012).

The goal of this study is to investigate how children of different ages reason about biological and nonbiological mechanisms of change. We are particularly interested in examining whether children's reasoning about life-span change as a biological process is influenced by the extent of change (e.g., physical growth and metamorphosis). We also ask to what degree children invoke essentialism as they reason about life-span change. Aspects of life-span change, particularly metamorphosis and sexual dimorphism, are two biological phenomena that ultimately led to the decline of essentialist models in formal biological theories (Mayr, 1982). It may be that, similarly, dramatic life-span change is initially difficult for children to incorporate into an essentialism-based theory of biological change. An important question is how children incorporate notions of dramatic change into their conceptual frameworks and how this relates to potentially deep commitments to essentialism (Gelman, 2003). We are particularly interested in examining how children's reasoning about these kinds of changes might be influenced by age and increases in knowledge. In the second half of our report, we explore how new knowledge of a particular type of dramatic change—metamorphosis—influences children's reasoning about biological change more generally.

We begin with a brief review of current perspectives on psychological essentialism. We then examine age and knowledge effects on reasoning about biological kinds and then describe the specific hypotheses of our study.

Psychological Essentialism

Essentialism, the notion that properties and characteristics of natural kinds stem from an underlying reality or "essence," has a long history in philosophy (Aristotle, 1924/1953; James, 1890/1983; Locke, 1671/1959) and biological science (Mayr, 1982). More recently, psychologists have viewed essentialism as a bias or constraint that influences the manner in which children and adults reason about a wide range of phenomena in the world (Birnbaum, Deeb, Segall, Ben-Eliyahu, & Diesendruck, 2010; Bloom, 2010; Gelman, 2003; Gelman & Markman, 1986; Hood & Bloom, 2008; Medin & Ortony, 1989). Proponents of psychological essentialism contend that the naïve biological theories of both children and adults incorporate the ideas that (a) all living things have an underlying essence, (b) this essence defines category membership, and (c) the essence is transmitted from parents to offspring (Ahn et al., 2001; Gelman, 2003; Gelman & Ware, 2012; Medin & Ortony, 1989; Sousa, Atran, & Medin, 2002).

The essentialist perspective just outlined is not without its critics. Some researchers suggest that children's natural kind categories are derived solely from observations of similarity (Sloutsky & Fisher, 2004; Sloutsky, Kloos, & Fisher, 2007). Others have suggested that reasoning about biological kinds operates on the basis of principled causal theories, as opposed to upon perceptual similarity, but that these principles need not take the form of psychological essentialism (Rips, 2001; Strevens, 2000).

While we acknowledge this debate regarding psychological essentialism, we use an essentialist frame for the current study because of its historical role in biology and especially in the understanding of evolution (Mayr, 1982). Specifically, we explore developmental differences in children's ability to categorize based on essences, or other nonobvious causal properties, in the face of dramatic perceptual change. Conversely, we use children's reasoning about biological kinds that undergo dramatic life-span change to shed light on their commitment to psychological essentialism.

Within the framework of psychological essentialism, Gelman and colleagues (Gelman, 2003; Gelman & Rhodes, 2012; Gelman & Ware, 2012) have articulated a set of core components related to essentialism. Here we focus on two of these components of essentialism (a) the idea that category identity is immutable in the face of changes to surface properties (Keil, 1989; Gelman & Wellman, 1991; Gottfried, Gelman, & Schultz, 1999; Johnson, 1990; Rosengren, Gelman, Kalish, & McCormick, 1991; Rosengren & Hickling, 2000) and (b) the idea that an essence gives rise to an innate potential to develop along predestined pathways (Gelman & Wellman, 1991; Hirschfeld & Gelman, 1997; Taylor, 1996; Taylor, Rhodes, & Gelman, 2009). This component is tied to the idea that the types of change an entity can undergo are domain and mechanism specific (Aristotle, cited in Wiggins, 1980; Keil, 1989; Rosengren et al., 1991; Schwartz, 1978). We view an understanding of dramatic life-span changes as an important piece of biological knowledge that may be very relevant to later understanding of evolution. Once children accept this knowledge (e.g., that caterpillars can turn into butterflies), they may be more willing to accept variation between parents and offspring, which in turn may lead to an understanding of species change. In this report, we examine the first part of this puzzle.

Researchers interested in psychological essentialism have generally treated it as a cognitive bias that operates across the life span. To date, little or no research has examined whether different components of essentialism emerge at different points or whether these components are influenced in important ways by knowledge and experience. In a cross-sectional study, French, Herrmann, Rosengren, and Evans (under review) found that certain components of essentialism (i.e., immutability, innate potential, and boundary intensification) emerge on different time courses, which suggests that essentialist reasoning is influenced by knowledge. The current study serves to both replicate this result by using a different task and stimuli set and to extend it by specifically examining how the acquisition of new knowledge might influence children's reasoning about biological change. If observational interventions are successful in influencing the extent of change in appearance allowed by children, as well as their understanding of underlying biological mechanisms, educational interventions that encourage understanding of both within-species and across-species variation may be only a terrarium away.

Age-Related Changes and Knowledge Effects in Biological Reasoning

Researchers have outlined extensively how children's general biological knowledge increases over childhood. Among the knowledge they acquire are properties and capabilities of specific categories of animals (Carey, 1985; Inagaki & Hatano, 1991), awareness of plants' status as living things (Angorro, Waxman, & Medin, 2008; Richards & Siegler, 1986), and knowledge of ecological and causal relations among species (Coley, Vitkin, Seaton, & Yopchick, 2005).

For example, Carey (1985) found that kindergartners performing an induction task with biological properties did not generalize properties to only those animals that actually possessed them, but rather generalized them broadly to living things. Specifically, children generalized properties such as "has bones," which should be attributed only to vertebrates, to both vertebrates and invertebrates. Seven-year-old children and adults, however, restricted their generalization to vertebrates. Inagaki and Hatano (1987, 1991) argue that older children's ability to limit the properties they transfer from humans to animals is due to increased knowledge of the biological world and of what phenomena specific biological kinds can undergo.

Although not designed explicitly to address the effects of knowledge on essentialism, past research does suggest that gains in knowledge may affect some of the essentialist biases under consideration in the current studies. For example, a close look at past growth and transformation studies reveals that, as children age, they are more likely to believe that category identity can be stable over dramatic surface change (Keil, 1989), and that dramatic changes in appearance can occur over the life span (Rosengren et al., 1991). In Keil's studies, when children were asked if a raccoon was still a raccoon when externally transformed to resemble a skunk, the youngest children denied that the animal was still a raccoon, and claimed that it was now a skunk (Keil, 1989). Similarly, when asked if a caterpillar would turn into a butterfly or simply would increase in size over growth, 3-year-olds favored the caterpillar becoming larger. Interestingly, in both cases, most of the researchers' focus has been on older children's willingness to reject that category membership changes with superficial changes in appearance (as in Keil, 1989) and older children's willingness to accept that identity is preserved over natural biological metamorphosis (as in the study by Rosengren et al., 1991). We argue that these changes in reasoning, like those just mentioned, are likely not only due to increases in age and general knowledge of the biological world but also to increases in knowledge about specific categories of biological kinds.

In one of the few studies to investigate explicitly the impact of direct experience on children's reasoning about biological kinds (see also Prokop, Prokop, & Tunnicliffe, 2008), Inagaki (1990) examined the influence that raising a goldfish has on children's inductive generalizations. Children who raised goldfish showed increased generalization from goldfish to other biological kinds, compared to children who had not had this experience. This work reveals that category-specific knowledge, in addition to a general essentialist bias, may drive categorization of and reasoning about natural kinds. The current study examines essentialist beliefs and the effects of category-specific knowledge in a cross-sectional experiment with a follow-up intervention. We expected to see a shift based on increased category knowledge in children's reasoning on the basis of components of essentialism—specifically, innate potential and category immutability—for organisms that undergo dramatic change.

Types of Change

We suggest that a number of different biological changes generally occur as part of natural life-span changes for different species, and here we describe four types of change that are investigated in this study. The first type of change is a naturalistic pattern of minimal growth that primarily involves an increase in size along with the relatively minor morphological changes associated with growth (e.g., kitten to cat). This is the type of change that Lorenz (1971) argued made humans feel affection towards animals that exhibit juvenile features (e.g., softer, smaller features, proportional differences) and is used to model morphological changes in facial features for orthodontia and facial reconstruction (Thompson, Krovitz, & Nelson, 2003). The second type of change consists of a pattern of growth that also involves changes in color and texture. For example, as a juvenile owl grows, the color and texture of its feathers change, making this change more dramatic than the minimal growth pattern, but its basic features such as a beak and wings remain constant. The third type of change is captured by classic metamorphosis. In this type of change, color, texture, and shape all alter significantly during growth. For example, a caterpillar undergoes a change to its body shape and acquires wings as it transforms into a butterfly. These natural types of change that occur over the life span of many biological organisms contrast with the fourth type of change investigated—the impossible changes that cut across typical category boundaries, such as a kitten morphing into an owl or a horse.

In the current study, we investigate children's acceptance of these different types of changes at three ages (3, 4, and 7). With 3- and 4-year-olds, we compared acceptance before and after experience with an example of metamorphosis. We also examined whether children would endorse both biological and nonbiological change for animals. In particular, we contrasted innate potential and immutability (e.g., biological organisms have to grow and change as part of the life cycle [Inagaki & Sugiyama, 1988]) with nonbiological mechanisms, such as magical change or change brought about by desire.

Consistent with previous literature (Rosengren et al., 1991), we predicted that children would be unlikely to endorse change in species type regardless of the mechanism involved. We also predicted that children would endorse natural biological change over nonbiological mechanisms of change, but that 3- and 4-year-olds would show this pattern less frequently than 7-year-olds. Finally, we predicted that direct exposure to caterpillars changing into butterflies would increase young children's use of biological mechanisms, particularly for items that undergo dramatic life-span change. In doing so, children may be provided with an early foundation for conceptualizing extensive evolutionary change over geological time. If children can accept that dramatic life-span change is caused by biological mechanisms, they may more easily grasp that variation within species is caused by biological mechanisms, and that this, over time, can lead to evolution.

Study 1

The current study examines the development of the propensity to use biological versus nonbiological reasoning about life-span changes of varying degrees. We predicted that children across age groups would offer more biological than nonbiological responses to all changes, but that 3- to 4-year-olds, due to lack of experience with living kinds that undergo dramatic change over the life span, would show less biological reasoning as the life-span changes become more dramatic. On the other hand, based on previous literature (e.g., Carey, 1985), 7-year-olds were expected to show biological reasoning near ceiling for all types of change.

Method

Participants

Twenty-six 3-year-olds (14 girls), ranging from 39 to 51 months (*M* = 47.2) and twenty-four 4-year-olds (12 girls), ranging from 46 to 53 months (*M* = 49.9), were recruited from a university laboratory preschool in a midsized Midwestern community in the United States. Twenty-six first-graders (12 girls) were recruited from a university-sponsored summer sports camp that drew broadly from the community. Exact birth date information was not available for these children, but all were in the 7-year-old range. As we expected these children to be at ceiling on our task, we report on the data collected from them even though we do not have a more precise measure of their age. The majority of children were from White, middle-class backgrounds.

Materials

Materials included 20 laminated photographs depicting the juvenile or adult forms of 10 different animal species drawn from a wide range on the phylogenic scale (dog, cat, horse, duck, owl, frog, butterfly; see Table 1).

Table 1. Examples of the juvenile and target adult forms presented for each type of change

Type of change	Juvenile form	Target adult forms	
		Correct form	Incorrect form
Growth			
Growth & color/ texture			
Growth & color/ texture & shape			
Species			 

Design and Procedure

Children were tested individually in a quiet area of the child's preschool by using procedures adapted from Rosengren et al. (1991). The experimenter began by familiarizing children with the difference between possible and impossible events by saying, "Some things can happen like I could draw on this piece of paper or walk out of this room. Other things can't happen. I can't walk on the ceiling or turn this chair into a bird." The experimenter then introduced the task by saying, "Now I'm going to show you some pictures of animals and ask you if the animals can change in different ways." Children participated in eight trials in which they were presented with a juvenile form of an animal, followed by two adult forms, and were subsequently asked questions about each adult form. As can be seen in Table 1, children were presented with juvenile and adult item sets that represented four different patterns of change, described earlier—growth; growth with texture and color changes; growth with texture, color, and shape changes; and impossible species change. Within each pattern of change were two juvenile-adult sets. Each set consisted of one juvenile and two adult items so that children saw a total of 8 juvenile and 16 adult items throughout the testing session. The item sets were presented in two orders, with children randomly assigned to one of these orders.

At the beginning of each trial, the experimenter presented children with a photograph of a juvenile animal, labeled with a unique proper name, and said, "Okay, here is a picture of [e.g., Jimmy]. Jimmy looks like this now." The experimenter then produced a picture of one of the adult animals and pointed to it, saying, "Could Jimmy ever change to look like this? Or will he always look like this [pointing again to the first picture]?"Children responded yes or no. In the three of the four patterns of change (growth, growth with color and texture changes, growth with color texture and shape changes), a response of yes was correct for one of the adult targets (i.e., puppy to dog) and incorrect for one of the adult targets (i.e., puppy to cat). In the impossible species-change trials, a response of yes was incorrect for either adult form (see Table 1).

For all trials, if the child responded yes, the experimenter asked five yes-or-no follow-up questions: Two were related to biological reasoning about the change living kinds undergo, and three were related to nonbiological (e.g., magical, psychological) ways of reasoning about the change living kinds undergo. The biological questions were "Could Jimmy grow up to look like that?" and "Does Jimmy have to change to look like that?" Research by Rosengren and colleagues (1991) has shown that these questions access biological reasoning, so we employed them here. Additionally, the wording of these questions—"grow up" and "have to change"—examined children's acceptance of innate potential and immutability of category identity. The remaining three questions—"Could Jimmy turn into that by eating special food?" "Could Jimmy turn into that because he really wanted to?" and "Could someone else make Jimmy turn into that?"—were used to assess children's acceptance of nonbiological changes. The "special food" question was designed to access magical reasoning about change, the "wanted to" question was designed to access psychological reasoning about change, and the "someone else make" question was designed to access change brought about by intervention. After answering these questions about the first adult form, children were presented with the other adult form, and the procedures were repeated. This was done for all eight trials. The order in which the two adult forms were presented was counterbalanced within each trial.

Coding and analysis. For each affirmative response to the correct adult target, participants were given 1 point. For each negative response to the *correct* adult target (e.g., puppy becoming dog), participants received no points. For each affirmative response to the *incorrect* adult target, participants received no points. Last, for each negative response to the *incorrect* adult target (e.g., puppy becoming cat), participants received 1 point. These scores were averaged to produce a correct adult score for each type of change. A 1 was recorded for each mechanism of change endorsed, and a 0 for each mechanism rejected. For each type of change, the correct adult score and the responses to the essentialist mechanisms (grow up, have to) were averaged to produce a biological reasoning score. The responses to the three nonbiological mechanisms (special food, want to, someone else make) were averaged to produce a nonbiological reasoning score.

Results

Figure 1 presents the results of this study. To examine the effect of different levels of change in children's willingness to reason biologically about living kinds, a 3 (Age: 3-, 4-, and 7-year-olds) × 2 (Reasoning: biological vs. nonbiological) × 4 (Type of Change: growth, growth & color/texture, growth & color/texture & shape, and species) repeated-measures analysis of variance (ANOVA) was conducted. Reasoning and type of change were within-subject measures. This analysis revealed main effects for type of reasoning, $F(1, 74) = 726.61$, $p < .001$, $\eta^2 = .91$, type of change, $F(3, 222) = 132.53$, $p < .001$, $\eta^2 = .64$, and age, $F(2, 74) = 4.79$, $p = .01$, $\eta^2 = .12$. As seen in Figure 1, across ages and types of change, children were more likely to endorse biological explanations for change ($M = .65$, $SE = .10$) rather than nonbiological explanations of

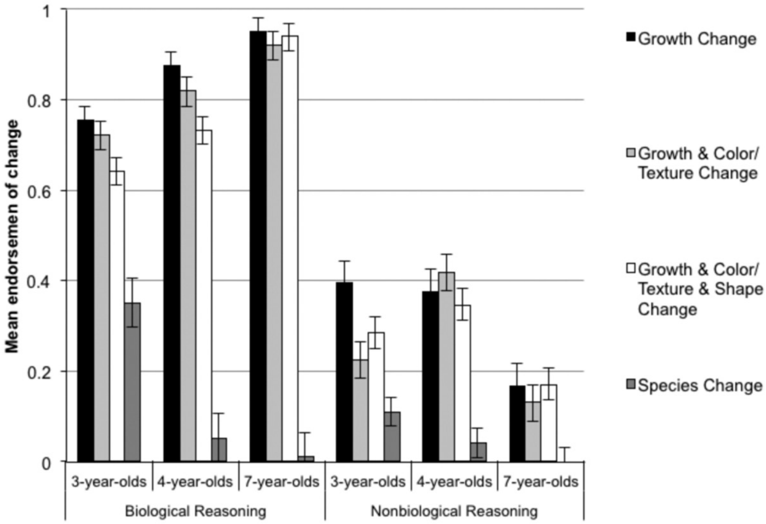

Figure 1. Study 1: 3-, 4-, and 7-year-olds' use of biological and nonbiological reasoning about different types of change in living kinds.

change (M = .22, SE = .02), p < .001. The main effect of type of change revealed that children at all ages were much less likely to accept either biological or nonbiological explanations for species level change (M = .26, SE = .02) than any of the other types of change (M_{Growth} = .59, SE_{Growth} = .02; $M_{\text{Growth \& T/C}}$ = .54, $SE_{\text{Growth \& T/C}}$ = .02; $M_{\text{Growth \& T/C \& Shape}}$ = .52, $SE_{\text{Growth \& T/C \& Shape}}$ = .02), all ps < .001.

These results were moderated by a number of significant interactions. (All interactions were followed up with post hoc comparisons using Bonferroni corrections.) We found a significant interaction between age and reasoning, $F(2, 74) = 25.60$, $p < .001$, $\eta^2 = .41$. Figure 1 shows that 3- and 4-year-olds exhibited similar patterns of theory endorsement and reasoned biologically more than nonbiologically. However, 7-year-olds (M = .12, SE = .03) were significantly less likely to endorse changes brought about by nonbiological mechanisms than were the other two age groups ($M_{\text{3-year-olds}}$ = .25, $SE_{\text{3-year-olds}}$ = .03; $M_{\text{4-year-olds}}$ = .30, $SE_{\text{4-year-olds}}$ = .03). As shown to the left in the figure, 7-year-olds (M = .70, SE = .02) were also significantly more likely to endorse changes brought about by biological means than were either 3- or 4-year-olds (both Ms = .62, SEs = .02), ps < .01.

The previous effects were moderated by a three-way interaction between theory, type of change, and age, $F(6, 222) = 5.52$, $p < .001$, $\eta^2 = .13$. As predicted, children's mean endorsement of biological mechanisms for texture, color, and shape changes increased with age. Figure 1 shows that 7-year-olds endorsed biological mechanisms at near ceiling levels for all three types of possible change: growth ($M = .95$, $SE = .03$), growth & texture/color change ($M = .92$, $SE = .03$), and growth & texture/color & shape change ($M = .94$, $SE = .03$). The 3- and 4-year-olds, however, endorsed biological explanations more for growth change ($M_{\text{3-year-olds}} = .76$, $SE_{\text{3-year-olds}} = .03$; $M_{\text{4-year-olds}} = .88$, $SE_{\text{4-year-olds}} = .03$) than for growth & texture/color & shape change ($M_{\text{3-year-olds}} = .64$, $SE_{\text{3-year-olds}} = .03$; $M_{\text{4-year-olds}} = .73$, $SE_{\text{4-year-olds}} = .03$), both ps $< .01$. The three-way interaction also suggests that 4-year-olds ($M = .05$, $SE = .06$) were significantly less likely to accept biological means of species change than were 3-year-olds ($M = .35$, $SE = .05$), $p < .01$. This type of change was also rarely accepted by 7-year-olds ($M = 0.1$, $SE = .05$). This result suggests that 3-year-olds are more accepting of impossible kinds of change than are older children. Another interesting result is that 3-year-olds ($M = .23$, $SE = .04$) generally were less accepting of nonbiological change involving growth and color/texture changes than were 4-year-olds ($M = .42$, $SE = .04$), $p < .01$. This result can be seen on the right-hand side of Figure 1.

Taken together, these results reveal that children at all ages studied favored biological over nonbiological processes when reasoning about the changes that a living kind undergoes as it develops. Nonetheless, the type of the biological change is important. While 7-year-olds endorsed biological reasoning at the same rate for all types of possible life-span changes, 3- and 4-year-olds were less likely to endorse biological means of change for dramatic changes such as metamorphosis.

Discussion

As found in previous studies (e.g., Rosengren et al., 1991), children as young as age 3 endorse biological reasoning about the growth of living kinds over a variety of life-span changes and largely reject both impossible changes (species change) and nonbiological mechanisms of possible life-span change. Strikingly, these results also reveal important differences between the biological reasoning of young and old children. Namely, 7-year-olds endorse innate potential and immutability at equally high levels for minimal and dramatic life-span changes, whereas 3- and 4-year-olds' use of these principles drops off with the amount of change an organism undergoes. For example, 7-year-olds were equally likely to say that a caterpillar "would grow up to be" or "had to become" a butterfly as they were to say a puppy "would grow up to be" or "had to become" a dog. However, 3- and 4-year-olds were less likely to endorse such statements about the caterpillar and butterfly pair than about the puppy and dog pair.

It appears that young children are both less and more constrained than older children in what types of change they are willing to accept. For example, 3-year-olds are less constrained than older children in that they accept species change and nonbiological changes at a higher rate than do older children. At the same time, 3-year-olds are less likely to accept biological changes in general than are older children. Compared to 4-year-olds, 3-year-olds were also less likely to accept nonbiological changes that involved growth combined with color/texture change, a type of change that is common in birds and other species. What these results suggest is that the types of change that children are willing to accept are probably driven by their knowledge and experience with the biological world. That is, between ages 3 and 4, children appear to be less willing to accept changes across species and, by age 7, are generally unwilling to accept nonbiological changes.

This cross-sectional investigation highlights age differences but does not enable us to tease apart whether these are due to knowledge gained or to some other developmental phenomena. In the next section, we directly test the hypothesis that these developmental changes are knowledge driven, by presenting children with an opportunity to witness dramatic life-span change firsthand.

Study 2

This study both directly tests the possibility that early biological reasoning is mediated by category knowledge and investigates the way in which early, possibly essentialist biases constrain learning about the biological world. Using similar stimuli and methods as in Study 1, we conducted an intervention to examine how familiarity with the life-span changes of a particular biological kind affects biological reasoning about a range of kinds. Children in this study received firsthand experience with caterpillars and witnessed them undergo metamorphosis into butterflies. The children also saw a pregnant mouse that gave birth to a number of babies. If essentialist reasoning, particularly reasoning about the innate potential of biological kinds, depends partly on knowledge of life-span changes, we expect to see an increase in children's biological reasoning after this exposure. However, if these reasoning biases are independent of knowledge about specific living kinds, then children's reasoning should show no change after the intervention. In this case, the differences between young and old children in Study 1 might be attributed to some other developmental phenomena.

Method

Participants

Fourteen of the twenty-six 3-year-olds (7 girls), ranging from 40 to 49 months (M = 46.4), and sixteen of the twenty-five 4-year-olds (8 girls), ranging from 51 to 56 months (M = 53.0), who participated in Study 1 were randomly selected to participate in Study 2. Additionally, fourteen participants (7 girls), ranging from 47 to 58 months (M = 52.14), from a preschool in upstate New York, served as the control group. All participants were predominantly middle-class Whites.

Materials

Materials were identical to those used in Study 1, except that different pictures of each species were used in the posttest.

Procedure

Pretest. The results of Study 1 served as the pretest data for the experimental group.

Intervention. After all children had taken the pretest, experimenters placed two glass terrariums in the their preschool classroom. The 3- and 4-year-olds were in adjoining classrooms, and the terrariums were placed in the middle of the two so that both classrooms had access to them. One contained painted lady caterpillars and the other contained a pregnant mouse. Over a 2-week period, children witnessed the caterpillars go through the stages of metamorphosis and become painted lady butterflies, and the mouse gave birth to a dozen pups. Children were able to visit the terrariums throughout the day and also drew pictures of the events in the terrariums intermittently over the 2 weeks. When the butterflies emerged from their cocoons, the teacher and children released them outdoors. While the terrariums were in the classroom, teachers were free to answer questions posed by the children regarding the animals but were not explicitly asked to provide any formal instruction about their growth, metamorphosis, or reproduction.

Control group. [1] Participants in the control group were given similar pretest and posttest tasks as the experimental group. However, the

1. The control group was obtained from a different sample. Although the procedure used was similar, we are cautious in our interpretation of the data.

control group did not have any animals in the classroom for observation. As with the experimental group, the stimuli received by the control group modeled dramatic and nondramatic life-cycle changes, but the control stimuli sets were different. The control group received 12 items (i.e., 6 possible transformations and 6 impossible transformations). Half of each of these transformations involved dramatic change, and half involved nondramatic change (i.e., typical growth).

Posttest. The posttest for the experimental group was conducted 2 months after the pretest. The method was identical to the pretest (Study 1), except that different photographs of each baby and adult species were used to prevent familiarity effects with the previous photographs. For the control group, because of scheduling issues, the posttest was conducted 1 month after the pretest. If repeated exposure to the stimuli explained the effect on the posttest scores, shorter intervals between pretests and posttests would increase scores as longer intervals would reduce the familiarity effect of the stimuli. Thus, the shorter interval of the control group can be considered a more conservative approach to the experimental design.

Results

To test our hypothesis that the intervention would increase biological reasoning and to assess the broadness of the intervention affect, we conducted a 2 (Age: 3- and 4-year-olds) × 2 (Test Time: pre- and postintervention) × 2 (Reasoning: biological and nonbiological) × 4 (Type of Change: growth, growth & color/texture change, growth & color/texture & shape change, and species transformation) repeated-measures ANOVA. Test time and type of change were within-participant factors. The analysis revealed main effects of time, $F(1, 28) = 6.93$, $p = .01$, $\eta^2 = .20$, reasoning, $F(1, 28) = 209.43$, $p < .001$, $\eta^2 = .88$, and type of change, $F(3, 84) = 155.04$, $p < .001$, $\eta^2 = .85$. We also tested for item effects, which did not reach significance.

Figure 2 displays the main effects for reasoning, type of change, and test time. As in Study 1, children were more likely to endorse biological mechanisms of change ($M = .63$, $SE = .01$) than nonbiological mechanisms ($M = .27$, $SE = .02$), $p < .01$, and were more likely to endorse the possible types of change ($M_{\text{Growth}} = .61$, $SE_{\text{Growth}} = .02$; $M_{\text{Growth \& T/C}} = .55$, $SE_{\text{Growth \& T/C}} = .02$; $M_{\text{Growth \& T/C \& Shape}} = .54$, $SE_{\text{Growth \& T/C \& Shape}} = .02$) than the impossible change ($M = .10$, $SE = .03$), all ps < .001. Children were also generally more likely to endorse change at posttest ($M = .48$, $SE = .02$) than at pretest ($M = .42$, $SE = .01$), $p = .01$.

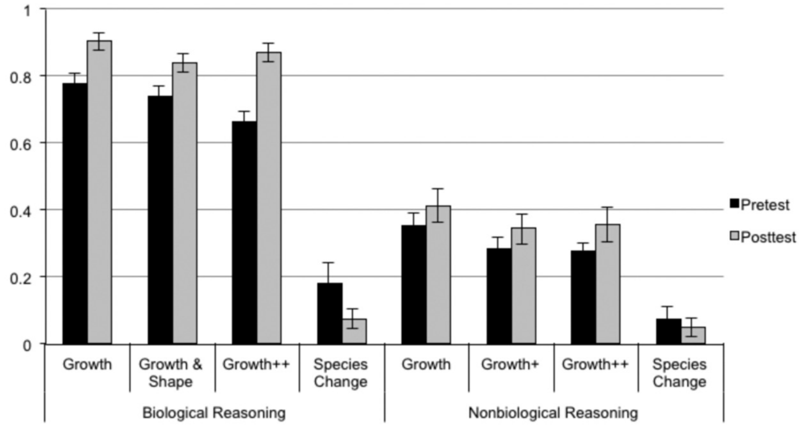

Figure 2. Study 2: children's use of biological reasoning about types of change before and after intervention. $*p < .01$; $**p < .001$.

These main effects were moderated by an interaction among reasoning, type of change, and test time, $F(3, 84) = 3.27$, $p = .03$, $\eta^2 = .10$, also displayed in Figure 2. This interaction was explored with post hoc comparisons with Bonferroni correction. Whereas no differences were found in children's endorsement of nonbiological mechanisms, significant increases between pretest and posttest were found in children's use of biological mechanisms for all three growth changes. Children's responses to biological questions increased for the baseline growth items ($M_{pre} = .78$, $SE_{pre} = .03$; $M_{post} = .90$, $SE_{post} = .03$), $p < .01$, the growth & color/texture change items, ($M_{pre} = .74$, $SE_{pre} = .03$; $M_{post} = .84$, $SE_{post} = .03$), $p < .01$, and the growth & color/texture & shape change items ($M_{pre} = .66$, $SE_{pre} = .03$; $M_{post} = .87$, $SE_{post} = .03$), $p < .001$. Responses to biological questions held steady, decreasing slightly, for the impossible change items ($M_{pre} = .19$, $SE_{pre} = .06$; $M_{post} = .08$, $SE_{post} = .03$), $p = .13$, signaling that children did not come to believe that any sort of life-span change is possible as a result of the intervention.

To pursue our focus on the breadth of the effect of category-specific information about biological changes, we conducted pairwise comparisons with the Bonferroni correction, examining children's essentialist responses to the caterpillar and tadpole items at pretest and posttest. The caterpillar was chosen because it closely resembled the caterpillars children witnessed at intervention, thus providing a test for within-category use of knowledge. The tadpole was chosen because it represents the same type of change (growth & texture/color & shape) as the caterpillar and allows us to ask whether children's knowledge of the dramatic life-span changes possible for caterpillars generalizes across category boundaries. Figure 3 reveals that, at pretest, children performed equally on the caterpillar ($M = .65$; $SE = .04$) and frog items ($M = .68$; $SE = .04$), $p = .48$, but that children's biological scores at posttest were significantly higher for the caterpillar item ($M = .92$; $SE = .04$) than for the tadpole item ($M = .82$; $SE = .03$), $p = .04$.

Control Group

At pretest, children in the control group got 8 of the 12 items correct and, at posttest, children got 9 of 12 items correct. This difference was not significant. These results suggest that repeated testing does not lead to improved performance.

Discussion

The results from Study 2 support our claim that an increase in knowledge about biological kinds drives the increase in children's belief in innate potential and immutability when reasoning about the life-span changes of

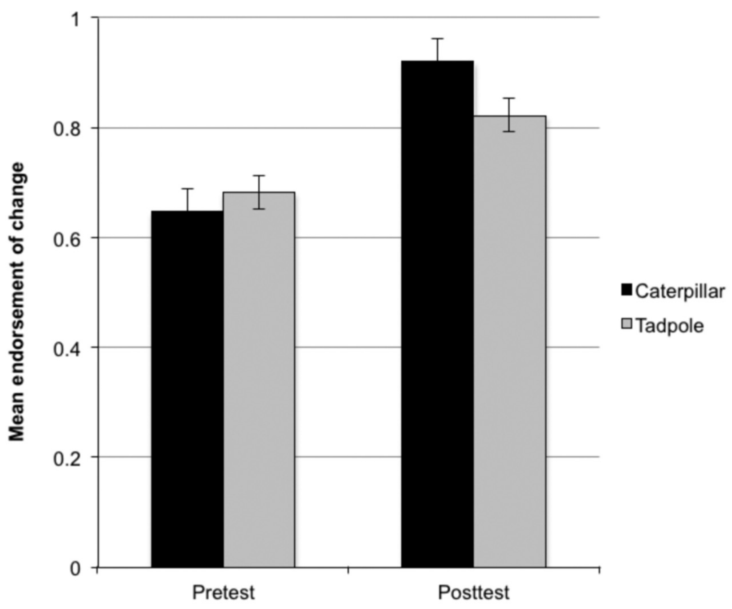

Figure 3. Study 2: The effect of intervention on children's endorsement of growth++ (growth and color/texture and shape change) for butterfly and frog items. $*p < .05$.

biological organisms (seen in Study 1). The intervention resulted in a broad increase in these beliefs across all possible types of life-span change and in a special increase for the subject of the intervention, the caterpillar. However, children did not begin to endorse species change, such as a kitten becoming an owl. Furthermore, children's endorsement of nonbiological mechanisms (magical, psychological) did not increase, suggesting that children understood the biological nature of the changes they witnessed during the intervention.

These results suggest that children learned both the necessity of growth and the possibility of transformation over the life span rather than a rule that any changes are possible. If children after the intervention had assumed that any changes were possible, they would have begun to endorse species change. Framed from the perspective of psychological essentialism, children's learning was constrained by essentialist biases. The bias of innate potential allowed children to accept dramatic changes over the life span of a species as biological, and the principle of boundary intensification restricted children's acceptance of biological change to within species.

Children's increase in biological reasoning for the caterpillar item, above and beyond the other growth & texture/color & shape change item, the tadpole, reveals the impact that witnessing the life-span change of a particular category has on biological reasoning about that category. Witnessing the transformation of a caterpillar into a butterfly raised children to near ceiling levels of biological reasoning as they became certain that part of the caterpillar's innate potential was transformation into a butterfly. Children neither witnessed a tadpole become a frog nor seemed to understand the biological necessity of this transformation. Furthermore, children in the control group had a relatively poor understanding of biological change compared to children in the intervention group. We feel this underscores the effect of biological knowledge rather than repeated testing. This is a clear demonstration of the importance of knowledge when one reasons about the innate potential and category immutability of biological categories that undergo dramatic life-span change.

General Discussion

The functioning of essentialism is and has been a fundamental issue for philosophers, psychologists, and science educators. It may be central to how we perceive and understand many aspects of natural categories (Gelman, 2003; Medin & Atran, 2004), taxonomy (Atran, 1998), and evolution (Gelman & Rhodes, 2012). Despite this centrality, little empirical work has investigated the possibility of a developmental progression in essentialist reasoning or the operation of its distinct components. If essentialist reasoning is a barrier to understanding and accepting evolution, it is important to understand the development of this form of reasoning. In the current studies, we investigated age-related and experience-related differences in beliefs about innate potential of biological kinds, and the immutability of the identity of biological kinds over transformations in appearance.

We presented 3-, 4- and 7-year-olds with animals that undergo a variety of life-span changes, from subtle to dramatic, and measured their essentialist reasoning about these changes, as well as their nonbiological reasoning about these changes. As in previous studies, all ages of children relied on biological models for explaining life-span changes more than nonbiological (magical, psychological) models. All ages of children also largely rejected the impossible life-span changes (speciation). However, older children showed more belief in innate potential and immutability when reasoning about life-span changes, particularly dramatic ones, than did younger children. This highlights for the first time a developmental progression in proposed components of essentialist reasoning.

The younger children were then presented with an intervention during which they witnessed the dramatic life-span change of a caterpillar becoming a butterfly. After this intervention, their biological reasoning increased significantly for all life-span changes. This provides strong evidence that the differences seen between young and old children in Study 1 are likely due to knowledge. This result has important implications for potentially breaking down some of the barriers to understanding and acceptance of evolution. Specifically, our results suggest that early exposure to natural biological changes leads to increases in knowledge of the range of changes that are possible. If this knowledge were accompanied by similar exposure to a natural range of variations across parents and offspring, one might be able to stimulate earlier understanding of evolution. Together, these studies highlight the necessity of real-world experience with living kinds in order for certain beliefs about biological kinds to manifest.

Additionally, our second study asked whether experience with the dramatic life-span changes of one particular kind would generalize to endorsement of life-span changes of other kinds. Children more frequently endorsed biological mechanisms of life-span change for the item witnessed during intervention (caterpillar) than for the other items with which they were presented. This suggests that the knowledge acquired about physical transformations of living kinds is both transferable and constrained. It is transferable in that witnessing the biological process of life-span transformation in one species increases confidence in the biological means of life-span change in related species. Specifically, children learn that appearance change can be part of the innate potential of certain living kinds, such as butterflies. But, this transfer appears to be constrained by knowledge of the specific changes that are allowable as part of a given organism's innate potential. That is, following exposure to caterpillars turning into butterflies, children did not begin to accept dramatic change for other organisms or increase their acceptance of nonbiological mechanisms of change.

Similar research by French, Herrmann, Rosengren, and Evans (under review) supports the findings of this report. These researchers investigated the endorsement of different models of within-species variation in young and old children and adults, presenting them with various levels of species familiarity and of species life-span change. The results revealed that more dramatic models of within-species variation were supported more as age increased. The results also revealed that, for unfamiliar categories, adults defaulted to choosing the growth model even for species that could be clearly identified as part of a larger class (e.g., insects) that generally undergoes more dramatic changes over the life span.

It has long been argued that the types of transformations believed to be possible for any entity are both domain and mechanism specific (Aristotle, cited in Wiggins, 1987; Keil, 1989; Rosengren et al. 1991; Schwartz, 1978). This study reveals the knowledge-based, developmental progression with which biological reasoning emerges, suggesting that what individuals view as acceptable transformations are not only domain and mechanism specific but also dependent upon knowledge of the biological possibilities in any given category. These results suggest that, in order to promote a greater understanding of evolution, children would benefit from hands-on examples of life-span change when learning about within-species variation, a key concept to understanding evolution.

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